Project no.: ***TREN/07/FP6EN/S07.73100/038406***

Project acronym: **CRISTAL**

Project title:

CONTROL OF RENEWABLE INTEGRATED SYSTEMS TARGETING ADVANCED LANDMARKS

Instrument: **Coordination Action**

Thematic Priority 6: SUSTAINABLE DEVELOPMENT, GLOBAL CHANGE AND ECOSYSTEMS

Title of report

Final (24 months) consortium report

Period covered: **from 10 December 2007 to 9 December 2009** Date of preparation: **07 February 2010**

Start date of project: **10th December 2007** Duration: **24 months**

Project coordinator name: Prof. Marcian Cirstea

Project coordinator organisation name: Anglia Ruskin University Revision: 1

1. Publishable Final Activity Report

1.1. Project execution

The Coordination Action aimed to contribute to the integration and strengthening of European research on Renewable Energy Sources and associated power converters, controllers and combined use. The project also aimed to contribute to securing a leading role for Europe in sustainable energy systems, strategically important to some EC Programme objectives such as: large scale implementation of Distributed Energy Resources (DER), energy storage technologies and systems for grid connected applications. At the same time, the proposed CA aimed to support the efforts made towards developing key enabling technologies for distributed energy networks with high power quality and security of service.

Within these overall aims, the specific activities of the consortium partners were focused towards the coordination of the research work related to the modelling, design, simulation and development of combined power system topologies based on renewable energy sources (wind, photovoltaic and micro-hydro), balanced by more stable energy storage systems (batteries, fuel cells and hydrogen) and their integrated control in conjunction with the grid. The activities were split into 4 workpackages, facilitating the exchange of expertise through short workshops, longer study visits, meetings, joint publications (IEEE OPTIM'08 conference special session organisation), events / presentations with public access organised by each partner institution and experimental demonstrations. The successful achievement of these objectives has pushed forward the frontiers of the current state-of-the art renewable power systems. The wider societal benefits include: i) increased awareness & enhanced knowledge on sustainable energy systems for participants and the general public, ii) correlated European research in DER, iii) identification of niche areas for further coordinated research, to comply with EC and national policies. Eleven institutions, from seven EU countries, formed the consortium, which carried out this project to completion:

Part. No.	Participant name	Short name	Country
1	Anglia Ruskin University - coordinator	ARU	UK
2	Aalborg University	AAU	Denmark
3	Politecnico di Torino	PUT	Italy
4	Environment Park S.P.A.	ENV	Italy
5	Transilvania University of Brasov	TUB	Romania
6	Warsaw University of Technology	WUT	Poland
7	University Politehnica Bucharest	UPB	Romania
8	Technological and Educational Institute of Patras	TEI	Greece
9	Cummins Generator Technologies	NAS	UK
10	Sustainable Technology Solutions Ltd.	STS	UK
11	Dublin Institute of Technology	DIT	Ireland

Distributed Electricity Generation (DEG) close to the end customer, differs fundamentally from the traditional model of an energy system consisting of large power stations, generating centrally controlled power. The DEG approach is new, replacing the concept of economy of scale using large units, by economy of numbers using many small units. There are needs / conditions to be met, as well as interconnection / integration requirements and test procedures to facilitate the interconnection and interoperability of DER and Electric Power Systems (EPS). Some of these were tackled by this project:

- Holistic control of distributed renewable generators in connection with the grid for power efficiency
- Ensuring quality of the power delivered, whether in islanded mode or connected to the grid
- Ensuring stability and security of service of DEG connected to the grid and meeting peak demands
- Identifying topologies enabling the optimal use and management of distributed generation and storage, in order to address existing / potential bottlenecks
- Establishing clear specification / performance criteria for modelling and design of integrated systems.
- Establishing clear test procedures for DR connected to the grid
- Application guides for the monitoring, information exchange and control of DR

The basic sample embedded generator system topology (Fig.1), targeted by the consortium's coordination activities, represents a distribution system for the end grid or autonomous users, containing several most available non-polluting renewable energy sources. It refers to a power generator with an efficient economical conversion system, controlled by a central unit, which provides maximum flexibility to control all power transfers between energy sources, users and grid. An experimental setup of such a renewable integrated system, efficiently controlled from a unique controller, exists at the West Beacon Farm (Nanpantan, Loughborough, Leicestershire, UK). This is one of the most advanced facilities in UK, which was set up thanks to the innovative vision and efforts of Prof. Tony Marmont, the owner of the Farm, in collaboration with the Centre for Renewable Energy Systems Technology (CREST) at Loughborough

University (represented at the time by Rupert Gammon). Prof. Marmont, a renewable energy champion in UK, has kindly made available to the consortium the parameters of the installations and has also granted partners access to the West Beacon Farm renewable facilities for demonstration purposes.

The project's activities were split into 4 workpackages, with an approximate symmetrical distribution, carried out in parallel for the entire duration of the project and interacting at key points.

- **WP1: Power Converters & Control Systems for Renewable Energy,** led by Politecnico di Torino
- **WP2: Photovoltaic & Micro-hydro Energy Systems,** led by Transilvania University of Brasov
- **WP3: Wind Energy Systems,** led by Warsaw University of Technology
- **WP4: Sustainability, Fuel cells, Hydrogen Technologies & Applications,** led by Sustainable Technology Solutions Ltd.

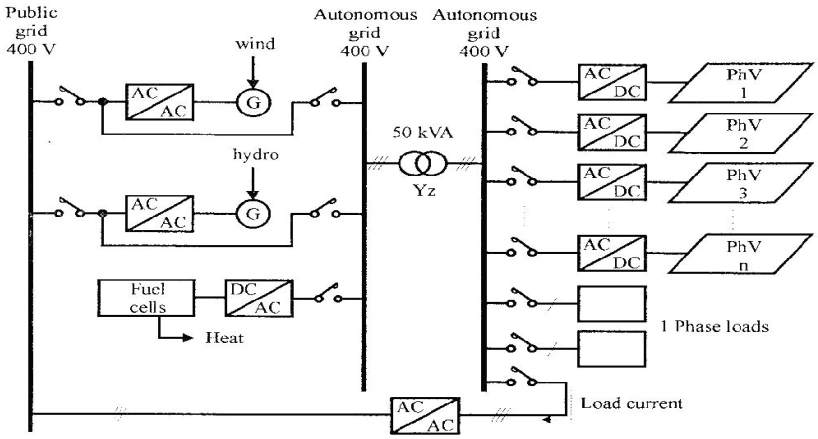

Fig. 1 Sample Renewable Embedded Generator Topology

Within its overall aims, this Coordination Action targeted the following **specific objectives**:

- The **coordination of the research work** carried out by the consortium members on Renewable Energy Sources (wind, micro-hydro and photovoltaic), power converters and associated controllers, their modelling and simulation, in view of integrating them and combining them with compensatory energy storage systems such as fuel-cells, hydrogen energy storage systems or batteries, connection to the mains grid and holistic control.
- The **contribution to the development of key enabling technologies** for distributed / smart energy networks with high energy efficiency, power quality and security of service, including analysis of needs for transmission systems, advanced power electronic converters and distributed storage systems for network applications. The activities will implicitly result in the **set up of an expert group**.
- The **enhancement of partners' knowledge** on Renewable Energy Sources and their integrated control and use, Sustainability, Distributed Renewable Generators and related issues.
- The **dissemination** of the **consortium's existing relevant work**, along with key issues related to the EC policy, National and International Energy programmes and the **increase of public awareness** on Sustainability / Renewable Energy Systems. The project has a public website hosted by Anglia Ruskin University, project coordinating institution (*http://www.anglia.ac.uk/cristal*). The website also includes a discussion forum, accessible to consortium members and the European Commission, upon request.
- The **facilitation of the renewable energy technologies transfer** from EU to recently accepted EU members (Poland, Romania) and also to make use of the existing expertise in these countries.
- The **implicit identification of common interests and niche areas,** where intensive further co-ordinated research is needed at European level, in order to address existing problems / difficulties and comply with EU directives and national governmental programmes for sustainable development.

The **coordination activities** carried out during the project are summarised below.

⇨ Setup of a publicly accessible project website by the coordinator from the start-up of the project *(http://www.anglia.ac.uk/cristal),* which includes a discussion forum (access restricted to consortium).

⇨ In the first round, 4 short visits between the institutions were organised, one in each workpackage, aimed at co-ordinating the current research activities carried out at individual institutions. Other objectives of the visits include sharing good practice in sustainable electricity generation and identifying common interests and clear topics for further (joint) research. The first round of visits mainly aimed at collating existing solutions to integrated control and grid connection.

⇨ A number of 2 longer duration (2 months) study visits from Romanian institutions (TUB, UPB) to EU countries (Denmark and Italy respectively) were achieved in workpackages 1 and 2, facilitating renewable energy technologies transfer from advanced EU member states to a newer member country. The individual study / analysis reports are included in General Meeting 1 proceedings.

- ⇨ The submission and acceptance through the peer review process of 16 jointly-authored papers (instead of the planned 8) to the IEEE OPTIM Conference, Romania, 2008.
- ⇨ Organising a special session on Distributed Energy Resources (DER) at OPTIM Conference, 2008. The 16 technical papers were presented by consortium researchers, focused on aspects of grid connection and the modelling, simulation and holistic control of integrated renewable generator topologies.
- ⇨ A first general meeting was organised in UK by the consortium co-ordinator, Anglia Ruskin University, with the participation of representatives from all institutions and the EC. This was a dissemination seminar, to present/share/co-ordinate findings from the first round of visits and the longer studies, thus correlating the existing research activities related to the DER and summarising the existing solutions. A visit to the Beacon Energy Farm also took place as a one day event, demonstrating to the participants renewables in practice / UK expertise in relation to the proposed topology for consortium investigations. Individual and workpackage reports were made available electronically and in printed format in the *General Meeting 1 Proceedings*. The meeting included a seminar on renewables, where the main non-confidential outcomes of the CRISTAL project were presented, along with several other presentations covering many aspects of renewables. Significant local players on renewable energy and sustainability were invited, either as presenters or participants. The guest lists included representation of the National Grid, major electricity distribution company (E.ON), small companies from the region and several other Framework 6 projects coordinated by the European Commission. The day ended with a very interesting Panel Discussion on energy matters. The panel consisted of Mr. Lewis Dale (UK National Grid, Chair), Mr. Richard Hair (E.ON) and Mr. Mario Dionisio (European Commission).
- ⇨ In the second round, 4 short visits between the institutions were organised, one in each workpackage, continuing the co-ordination of the current research activities carried out at individual institutions and the sharing good practice in sustainable electricity generation. Whereas the first round of visits was mainly focused at collating existing solutions to integrated control and grid connection, this second round of visits also discussed the advantages and disadvantages of such work carried out by the partners, by critically analysing the existing models and systems, proposing solutions for improving their operation, efficiency, stability and holistic control. An important outcome was also the identification of issues that still need addressing, through coherent and focused further research.
- ⇨ Eleven local events / seminars, open to the general public, were organised. These raised public awareness on sustainability, renewable energy sources, European policy, national and international priorities and also disseminated technical results of research developed by the partner institutions and the main findings collated / coordinated through the CRISTAL project activities. The events were either organised individually, by the respective partner, or jointly with other local players in renewables (where appropriate), in larger conferences, co-sponsored by the CRISTAL project.
- ⇨ A general conclusive meeting was organised at the end of the project, with the participation of representatives from most institutions (except STS and NAS). The technical findings of the second year exchange visits were presented and discussed. In addition to collating and reviewing existing solutions, advantages and disadvantages were highlighted, by critically analysing the existing models and systems, proposing solutions for improving their operation, efficiency, stability and holistic control and identifying issues that still need coherent and focused research work to be performed. The organisation of the local public events, to raise general awareness on sustainable energy generation, was reported and discussed. This final general meeting was hosted by TEI, Greece. Each participant (institution) has prepared an institutional final report and the workpackage leaders have each produced a workpackage final report and presented a summary workgroup report. The reports were collated into the *Meeting 2 Proceedings*. A CDROM (specially designed to include all outputs from CRISTAL) and hard copies of the proceedings were distributed to participants and made available to the EC.

Project Achievements and Conclusions

The technical discussions during the meetings allowed excellent exchange of knowledge regarding distributed generation, identifying the right solutions to tackle the most important issues in the field of power electronics topologies and their control. The organisation of a special session on Renewables and Sustainability at the IEEE OPTIM'08 conference, where 16 (instead of 8 planned) CRISTAL papers were presented, placed in the public domain significant technical knowledge from the consortium.The exchange of knowledge and good practice during the workshops and the visits to different renewable energy plants and sites offered a splendid opportunity to complete and enrich each participant's knowledge in the field of Renewable, to compare and find new ideas for solving "old" problems.

The project enabled the interaction with other significant players in distributed renewable energy through: i) the technical visits to third parties and local companies, ii) the local events open to the public, iii) the participation in an event organised by the European commission on grid related projects, and iv) the research seminar organised during general meeting 1, where CRISTAL project non-confidential knowledge was disseminated beyond the consortium boundaries and was enriched through contributions from the national grid (UK), major energy companies (E.ON), several presentations from smaller local players

(Sustainable Technology Solutions Ltd., Bryte Energy Ltd., Renewables East Ltd., University of Nottingham) and three other Framework 6 European projects: WINDGRID, IS-POWER and VSYNC.

The first year was more about presentation of existing activities and the partners getting to know each other and finding potential avenues and topics of cooperation, whereas the second year was focused more on critical analysis of the existing models and systems and proposing solutions for improving their operation, efficiency, stability and holistic control. Two significant technical reports were produced after the two long study visits: i) *Holistic modelling of integrated power systems connected to the Grid (48 pages)* and ii) *Optimal power electronics topologies and controller to achieve quality of the power delivered to the Grid in photovoltaic and micro-hydro systems (33 pages)*. The partners also reached the desired objective related to establishing clear specifications and performance criteria, on both modelling and design of integrated systems and have produced a document summarising the Grid connection criteria. An important outcome was also the identification of issues that still need addressing, through coherent and focused further research work. Good and effective collaborative work was carried out throughout the project, achieving all project objectives and creating a renewables expert group.

1.2. Dissemination and use

The work developed by the partners in the CRISTAL consortium led to the following:

- Project website, hosted by Anglia Ruskin University, which includes a project summary presentation (http://www.anglia.ac.uk/cristal) and a discussion forum (restricted to consortium members).
- 16 collaborative scientific papers co-authored by the consortium members were presented in the special session on Renewables and Sustainability of the IEEE OPTIM conference, Brasov, Romania, May 2008, and are indexed by the IEEE Xplorer digital library, placing in the public domain significant scientific & technical information and know how from the project consortium.
- The detailed technological findings of the CRISTAL coordination activities have been summarised in individual short visit reports, the two long term (2 months) study visit reports, and the two general meeting proceedings (800+ pages), distributed to the EC and the consortium members.
- A day seminar was organised as part of the general meeting 1, where the non-confidential project findings were disseminated to local and regional body representatives, as well as representatives from other Framework 6 European projects on renewables (VSYNC, WINDGRID, IS-POWER).
- Research students at consortium partner institutions were stimulated by the CRISTAL activities in their research degrees (Ana Maria Dumitrescu, UPB) and several of them obtained doctorates, placing CRISTAL related knowledge in the public domain (Cesare Pica, PUT, 2008, Leonardo Limongi, PUT, 2009, Luminita Barote, TUB, 2009, Catalin Petrea Ion, TUB, 2008, Ioan SERBAN, TUB 2008).
- Other dissemination was achieved through: **i)** consortium partner websites, **ii)** the submission and presentation of many papers from 7 of the consortium partner institutions at the IEEE International Symposium on Industrial Electronics, **iii)** joint-authored publications to conferences (IECON'09, EPE'09, EVER'09, ISIS'10, ISIE'10, OPTIM'10) or in journals, **iv)** Prof Marinescu's participation on the behalf CRISTAL consortium to the Electricity Grid workshop "TREN-GRID-WORKSHOP-2009", organised by the European Commission *Unit D2- Energy Technologies and Research Co-ordination,* 2nd April 2009, **v)** a dedicated CRISTAL journal article to be published in a special edition focused on EU projects by British Publishers Ltd.

It can be concluded that the CRISTAL project has had significant achievements in the coordination of the research work carried out by the consortium members on renewables, the enhancement of partners' knowledge on Renewable Energy Sources and their integrated control and use, which contributes to the development of key enabling technologies for distributed/smart energy networks. The dissemination of the consortium's relevant work was also achieved through various mechanisms, along with the facilitation of the renewable energy technologies transfer from established EU countries to new EU members (Romania, Poland). The identification of common interests and niche areas, where intensive further coordinated research is needed at European level, is also an important outcome.

For more information about the project, please visit http://www.anglia.ac.uk/cristal or contact the Project Co-ordinator, Prof Marcian Cirstea. He would like to address his sincere thanks to the workpackage leaders, the other project partners and the European Commission, for the efforts dedicated to CRISTAL.

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